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LABORATORY CHEMICAL COAGULATION STUDIES ON THE REMOVAL OF FALLOUT RADIOACTIVITY IN WATERS

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A résumé of laboratory studies on the removal of soluble or colloidal radioactivity from water by coagulation, settling and filtration to simulate conventional American water works practice was reported by Straub(1). Most of these studies were made by adding specific radioisotopes or mixtures of isotopes to synthetic or natural waters prior to coagulation and testing by conventional laboratory methods(2). In general, the levels of activity in the test water were high (estimated activity of 25,000 to 15,000,000 uuc/l) as compared to the continuous use maximum permissible level of 100 uuc/l for unidentified mixed activity(3). At these levels observed activity removals in excess of 99 per cent, if attained, would therefore be considered unsatisfactory.

Bomb debris consists of mixed fission products and induced activity. It is physically and chemically dissimilar to mixed fission products in acid solution. It can be postulated that changes in its chemical composition and behavior, exclusive of normal decay, occur through the process of weathering and adsorption before and after deposition on the earths surface (either as dust or precipitation) where it may become a water contaminant. Reported observations on the removal of this type of water contamination are few(4)(5)(6) with results indicating removal of 35 to 80 per cent of the fallout by coagulation, settling, and filtration.

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It is the purpose of this paper to summarize the laboratory jar tests on chemical coagulation for removal of radioactive materials found in Cincinnati rain, cistern water, surface water, and rain leachings through native soils. Included in the study are results of coagulating carbonated and noncarbonated distilled water extracts of an alkaline soil contaminated with bomb debris.

Methods Used

In general, the coagulation studies were performed by treating a 1.5 liter sample in a wide mouth, square-based, pickle jar. A variable speed six-unit laboratory paddle-stirrer was used to provide a 1-2 minute rapid mix upon addition of chemical coagulant followed by a slow 20-30 minute flocculation period. A freshly prepared solution of alum ($Al_2(SO_4)_3 \cdot 8\ H_2O$) was added to the sample with or without clay, the clay to provide for adsorption of beta activity or nuclei for floc formation. The pH of the mixed liquor was determined and the nature of the floc observed during mixing. Following flocculation, the samples were settled for 30-60 minutes with one-half of the sample being decanted and filtered through Whatman No. 42 paper. The filtrate was evaporated to near dryness and the solids were transferred to dishes for counting.(7) Where necessary, corrections for self-absorption and decay were made.

Immediately after decanting one-half of the sample from the first coagulation, the remainder of the sample and all of the floc from the first coagulation were alkalinized with lime slurry from freshly slaked CaO. Following rapid and slow mixing for 20-30 minutes and quiescent settling for 30-60 minutes a second decant was removed, filtered, and tested as described for the first filtrate.

Floc formation was observed as pin point in size and nonsettleable (x) to large rapidly settling floc (4x). Occasionally, because of poor floc formation or low pH, additional chemical was added during flocculation to adjust for optimum coagulation at minimal chemical dose. In other instances where large samples were available, particularly with cistern waters, chemical dose was varied and other chemicals, such as tri-sodium phosphate or ferric sulfate, were used to investigate conditions for maximum removal of beta activity.

In the case of soil extracts and some rain, samples of 1 liter or less were used for alum coagulation and, where available, a second liter was used for alkaline-alum coagulation.

Results of Coagulating Rain, Cistern, and Surface Waters

The results obtained in coagulating 12 Cincinnati rain samples are presented in Tables 1 and 2, and show a variation in total beta activity ranging from 795 to 31,900 uuc/l of 8- to 22-day old nuclear bomb debris. Except for a few samples it may be noted that all of the suspended and part of the dissolved beta activity were removed by coagulation. Total removals by alum coagulation below pH 7 appear to be superior to alum coagulation at high pH. This observation appears to indicate that activity associated with suspended solids is more leachable at higher pH values but it does not exclude the possibility that coagulation at high pH has effected more complete removal of soluble alkaline earths such as Sr^{89}, Sr^{90}, and Ba^{140}.

Six cistern waters representing settled rain in which particulate matter has had extended contact with water were coagulated with the results

indicated in Tables 3, 4, and 5. Table 3 shows that ferric sulfate is no more effective as a coagulant than alum. Neither increased concentration of clay nor of carbon significantly alters the overall removal of suspended or dissolved beta activity. Alum-lime-phosphate treatment at high pH (9.2 - 10.7) was equal to or slightly better than alum with either clay or carbon at coagulation pH of 6.8 to 8.4.

A comparison of the results given in Table 4 indicates that trisodium phosphate in cistern water coagulated with alum at pH 6.7 to 7.0 was inferior to ferric sulfate-phosphate coagulation at pH 4.7 to 9 and alum coagulation at pH 6.6 to 7.7.

Alum or ferric sulfate plus phosphate plus lime at pH values 9.2 to 10.7 was superior to any other combination of chemical coagulants. The total chemical dose however was high, varying from 63 to 93 ppm.

The results presented in Table 5 show greater variation in total and dissolved removals. The results of tests 1-4 on samples low in total and dissolved beta activity show that the percentage removal by coagulation is substantially inferior to the more radioactive cistern waters.

Seven surface waters consisting of Ohio River water, lake water from impoundment of a local stream, and four Cincinnati rain water leachings through native sandy or clay loam soils were coagulated. Since most of the rain radioactivity had been removed by the natural process of adsorption and sedimentation or percolation, the residual dissolve radioactivity represented the most difficult fraction to remove by coagulation.

The results, presented in Table 6, show a removal of 30 to 76 per cent of the total beta and from 6 to 48 per cent of the dissolved beta in all samples except the Ohio River water filtrate. The river water filtrate was more radioactive after coagulation than before.

Results of the rain, cistern, and surface water studies are summarized in Table 7 for an overall comparison of the many pertinent factors contributing to the extreme variability of removals achieved in the laboratory jar test studies. The average removal of total activity increases from about 50 per cent for surface waters to about 75 per cent for rain water relatively high in suspended activity. Over the range of chemical dosages used, there appears to be little benefit in coagulation at any particular pH value, although high chemical doses at high pH values often showed measurable decrease in the removal of dissolved beta activity.

Results of Coagulating Soil Extracts

A soil* containing 263 uc of 7-month old nuclear bomb debris per kilogram of dry sample was separated into six fractions using standard sieve size numbers 8, 20, 40, 70, and 90. Each soil fraction was serially extracted initially with distilled water and subsequently with carbonated water. From six extractions of each soil size, it was determined that 1.1 uc/kilogram soil went into solution and 15.2 uc was associated with non-settleable suspended matter in about 25 liters of extractant. The finer sized grains contained a much higher per cent of both soluble and suspended beta activity.

* Furnished through the courtesy of O. R. Placak, USPHS-AEC, Las Vegas Field Office, and R. L. Woodward, Chief, Water Supply, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.

The first two serial extractions with distilled water produced comparable beta activities, suspended solids, and pH values for a given soil size, i.e., total beta activities of 60 to 450 uuc/ml, total solids of 100 to 600 ppm, and pH values of 8.0 to 9.0 for the coarse to fine soil fractions respectively.

Five hundred ml portions from each of these 12 extracts were coagulated with from 80 to 120 ppm of filter alum at pH values varying from 6.1 to 7.4. The samples were then treated with 40 ppm CaO for the second coagulation step at pH values of 8.9 to 10.4.

The third extraction of the series was made with distilled water and carbon dioxide bubbled into the soil slurry at intervals to maintain a pH of 6 to 7 over a 12-day period. The slurries were shaken, settled for 30 minutes, and the supernatants decanted. Five-hundred ml samples of each of these decantates were coagulated with 40 ppm alum and, after removing one-half the supernatant, with lime in the presence of the alum floc as described in treating the rain and cistern waters.

In the tests on soil extracts it was assumed that settled extracts would simulate rainout or fallout in runoff. However, only a small per cent of the soil contamination was suspended or dissolved.

There appeared to be no significant correlation between the chemical dose, the pH of coagulation or the level of beta activity on the removal of <u>total</u> activity by either alum or alum-lime coagulation. The 12 tests of distilled water and the six tests of carbonated water extracts were therefore considered to be two similar types of samples, the results of which are summarized in Table 8.

A second set of coagulation tests on soil extracts was made when the bomb debris was 9 months old. In this case the extracts from each size fraction of a serial extraction was combined to provide a stock suspension. Numbers 1 through 6 and 8 were serial distilled water extracts of two days or more, except No. 3 which was a 30- to 45-minute wash to separate the fine particles from the soil fraction (note the high suspended solids). Extract No. 7 was made with distilled water and carbon dioxide as previously described.

Liter samples of the stock suspensions were coagulated for 30 minutes with alum at pH 4.5 to 7.4 and separate liter samples were alkalinized with lime to pH 10.0 to 11.1 for 20 minutes before they were coagulated with alum for 30 minutes. Clay (Apatite) was added to some of the extracts. Seven of the filtrates were tested for strontium-90 to determine preferential removals of this isotope.

The results of these tests are presented in Table 9. The first six serial extractions with water show a progressive decrease in the dissolved beta activity whereas the total beta activity fluctuated, depending primarily on the suspended matter separated by decantation. The carbonic acid extract No. 7 had about three times as much dissolved beta activity and dissolved solids as the distilled water extracts.

When the extracts were coagulated with 40 to 80 ppm alum at near neutral pH, the removal of total activity varied from 72.6 to 98.9 per cent, depending in part on the amount of suspended beta activity. These values are comparable to the results shown in Table 8. Assuming that

all of the suspended activities were readily removed by coagulation, it was calculated that alum coagulation at pH 6.9 to 7.4 removed 24.6 to 49 with an average of 36.6 per cent of the dissolved activity. The removal of dissolved activity in extract No. 4 by alum coagulation at pH 4.5 was 74.3 per cent. The extract contained only 14 ppm of suspended solids so the floc from 80 ppm alum was largely $Al(OH)_3$..

The strontium-90 content of the filtrate of alum coagulated samples was determined on extracts No. 1, 4, 7, and 8 and varied from 140 to 1190 uuc/liter as compared with the longtime use of strontium-90 MPC value of 800 uuc/l[3]. The per cent of strontium-90 activity in the filtrate varied from 11.6 to 15.1.

Lime-alum coagulation consisted of adding lime slurry and mixing for 20 minutes to allow chemical interaction with soluble elements before dosing with alum and coagulating for 30 minutes. The filtrate activity for all but the carbonic acid extract was comparable to the filtrates from alum coagulation with observed removals of all of the suspended and 17.6 to 60 or an average of 38.4 per cent of the dissolved activity.

The carbonic acid extract, No. 7, chemically precipitated with 224 ppm of lime (CaO), produced far better activity removal (all of the suspended and 81.9% of the dissolved). Even with this high degree of removal, the filtrate had 2200 uuc/l of beta activity of which 7.3% or 160 uuc/l was strontium-90.

Comparing the strontium-90 in the lime-alum filtrates to that in the alum filtrates, it is noted that lime-alum filtrates contain 1/2 to 1/5 the strontium-90 found in the alum filtrates.

An attempt was made to correlate the percentage removal of total and of dissolved beta activity with the pH of coagulation, assuming other variables of water quality and coagulant dose would cancel each other. The data for these correlations presented in Table 10 were arranged in the three pH ranges of 4-7, 7-9, and 9-11 for the four types of water coagulated. Considering median and average values, the differences in the total beta removal are insignificant for the three pH ranges. A somewhat greater percentage total beta removal was obtained with the soil extracts samples (7- to 9-month old material of high activity) with removals in the order of 90 per cent as compared to 75 per cent for rain water, 65 per cent for cistern water, and 50 to 60 per cent for surface water and soil leachings. The percentage removal of dissolved beta is extremely variable. All of the suspended activity and 25 to 35 per cent of the dissolved activity are removed from rain, cistern, or surface water samples. In soil extracts at activity levels of 10,000 to 350,000 umc of total beta per liter and 4,000 to 15,000 umc of dissolved beta per liter, coagulation removed on the average all of the suspended and 35 to 55 per cent of the dissolved activity.

SUMMARY

Over a three-year period radioactive rain, cistern and surface waters collected in the Cincinnati area have been coagulated with alum, hydrated lime, and coagulant aids in various combinations and pH values

for the removal of fallout activity. Water extracts of a soil contaminated with nuclear bomb debris was similarly coagulated. The laboratory jar tests with chemicals and dosages used in conventional water treatment practice indicate that all of the suspended beta activity and part of the soluble beta activity is removed. The longer the activity has been subjected to natural purification (adsorption on surfaces, sedimentation, percolation, etc.) the more difficult it is to remove the remaining soluble activity by coagulation.

Coagulation with lime and alum at about pH 10 favors the removal of alkaline earth isotopes such as strontium-90.

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Table 1: Coagulation of Low Activity Rain

TEST	1	2	3	4	5	6
QUALITY OF WATER						
Total solids, ppm,	30	30	110	123	--	13
Dissolved solids, ppm,	12	12	86	28	72	tr
pH,	--	--	7.5	8.2	--	7.4
Age of bomb debris, days	14	14	22	14	8	22
Total beta, uuc/l,	795	795	801	1160	4510	4530
Dissolved beta, uuc/l	185	185	316	450	910	1630
I - ALUM COAGULATION						
Clay added, ppm,	27	40	38	15	--	50
Alum added, ppm,	13	26	19	15	21	25
Lime added, ppm,	--	--	--	--	36	--
Floc formation,	4x	4x	4x	4x	4x	4x
pH,	7.2	6.6	7.0	7.3	6.8	6.4
Ia - ALKALINE COAGULATION						
Lime added, ppm,	32	--	--	53	33	--
Alum added, ppm,	16	--	--	27	--	--
Floc formation,	4x	--	--	4x	--	--
pH,	5.4	--	--	5.3	8.2	--
TOTAL BETA REMOVALS, %						
I Alum Coagulation,	80	75+	71	73	84	77
Ia Alkaline Coagulation,	77	--	--	71	77	—
DISSOLVED BETA REMOVALS, %						
I Alum Coagulation,	13	(-8)	27	31	20	35
Ia Alkaline Coagulation,	3	--	--	25	(-15)	—

Table 2: Coagulation of High Activity Rain (2)

TEST	1	2	3	4	5	6
QUALITY OF WATER						
Total solids, ppm,	32	32	18	20	20	65
Dissolved solids, ppm,	28	28	6	14	14	29
pH,	6.8	6.8	6.4	6.3	6.3	6.8
Age of bomb debris, days	22	22	12	12	12	12
Total beta, uuc/l	3150	3150	18450	31900	31900	26300
Dissolved beta, uuc/l	1300	1300	8450	8500	8500	9600
I - ALUM COAGULATION						
Clay added, ppm,	27	27	40	--	--	40
Alum added, ppm,	27	40	20	13	20	20
Floc formation,	2x	2x	x	3x	3x	2x
pH,	5.6	5.2	6.0	5.8	5.5+	5.7
Ia - ALKALINE COAGULATION						
Lime added, ppm,	16	16	27	16	29	27
Floc formation,	4x	4x	2x	3x	3x	3x
pH,	9.8	8.9	8.6	7.8	8.2	8.7
TOTAL BETA REMOVAL, %						
I - Alum Coagulation	62	72	83	80	80	81
Ia - Alkaline Coagulation	71	75	86	62	59	83
DISSOLVED BETA REMOVAL, %						
I - Alum Coagulation	8	33	63	30	31	48
Ia - Alkaline Coagulation	31	38	69	(-33)	(-40)	55

Table 3: Coagulation of Cistern Water
(Total solids-35 ppm, Dissolved solids-30 ppm, pH-6.8, 26 day-old bomb debris, Total beta activity-2460 uuc/l, Dissolved activity-1180 uuc/l)

TEST	1	2	3	4	5	6
I ALUM COAGULATION						
Clay added, ppm,	13	13	13	40	40	40
Lime added, ppm,	7	13	13	7	13	13
Alum added, ppm,	13	20	27	13	20	27
Floc formation,	4x	3x	4x	4x	4x	4x
pH,	6.9	7.9	8.0	7.9	8.4	8.2
Ia CONCURRENT PHOSPHATE-LIME COAGULATION						
Na_3PO_4 added, ppm,	8	8	8	8	8	8
Lime added, ppm,	32	32	32	32	32	32
Floc formation,	4x	3x	4x	4x	3x	4x
pH,	10.6	10.6	10.6	10.6	10.6	10.6
II FERRIC SULFATE COAGULATION						
Clay added, ppm,	13	13	13	27	27	27
$Fe_2(SO_4)_3$ added, ppm,	13	27	40	13	27	40
Floc formation	4x	3x	xx	4x	4x	4x
pH,	6.4	5.0	4.3	6.4	5.7	4.9
III ALUM-ACTIVATED CARBON COAGULATION						
Carbon added, ppm,	7	7	7	20	20	20
Lime added, ppm,	7	7	7	7	7	7
Alum added, ppm,	13	27	40	13	27	40
Floc formation,	4x	x	xx	4x	4x	4x
pH,	7.1	6.2	6.5	6.8	7.0	6.9
IIIa CONCURRENT PHOSPHATE-LIME COAGULATION						
Na_3PO_4 added, ppm,	7	7	7	7	7	7
Lime added, ppm,	13	13	13	13	13	13
pH,	10.3	10.1	10.2	10.6	10.6	10.6
TOTAL BETA ACTIVITY REMOVAL, %						
I Alum + Clay	62	62	65	66	66	70
III Alum + Carbon	64	64	67	63	67	66
II Ferric sulfate	62	62	57	62	62	57
Ia PO_4-Lime	63	66	54	72	66	67
IIIa PO_4-Lime	62	65	68	64	69	64
DISSOLVED BETA ACTIVITY REMOVAL, %						
I Alum + Clay	21	21	28	30	30	27
III Alum + Carbon	24	25	31	22	31	30
II Ferric sulfate	27	26	10	27	27	19
Ia PO_4-Lime	22	29	4	42	30	32
IIIa PO_4-Lime	22	27	32	25	36	24

Table 4: Coagulation of Colored Cistern Water
(Dissolved solids-33 ppm, Total solids-43 ppm, pH-6.4, high color, low surface tension, 25 day-old bomb debris, Dissolved Beta-1910, Total beta-3200 uuc/1).

TEST	1	2	3	4	5	6
I ALUM COAGULATION						
Clay added, ppm,	13	13	13	40	40	40
Lime added, ppm,	7	13	13	7	13	13
Alum added, ppm,	13	20	27	13	20	27
Floc formation,	3x	4x	4x	4x	4x	4x
pH,	6.6	7.6	7.4	6.8	7.7	7.3
II PHOSPHATE-ALUM OR FERRIC SULFATE						
Na_3PO_4 added, ppm,	33	33	33	33	--	--
Lime added, ppm,	--	--	--	--	13	13
Carbon added, ppm,	13	7	20	27	13	27
Alum added, ppm,	13	13	20	--	--	--
$Fe_2(SO_4)_3$, ppm,	--	--	--	40	13	40
Floc formation,	2x	3x	4x	4x	4x	4x
pH,	7.0	6.9	6.7	4.7	9.0	4.9
IIa EXCESS LIME						
Lime added, ppm,	13	13	13	13	--	13
Floc formation,	4x	4x	4x	4x	--	4x
pH,	10.2	10.7	10.7	9.2	--	9.8
TOTAL BETA ACTIVITY REMOVAL, %						
I Alum Coagulation	65	66	69	66	63	71
II PO_4-Alum	48	45	60	58	64	60
IIa Excess Lime	69	70	72	81	--	69
DISSOLVED BETA REMOVAL, %						
I Alum Coagulation	41	43	48	42	38	51
II PO_4-Alum (iron)	13	8	33	30	40	33
IIa Excess Lime	48	49	53	68	--	49

Table 5: Coagulation of Cistern Waters

TEST	1	2	3	4	5	6	7
QUALITY OF WATER							
Total solids, ppm,	126	126	46	46	41	41	41
Dissolved solids, ppm,	62	62	41	41	36	36	36
pH,	6.4	6.4	6.2	6.2	6.0	6.0	6.0
Age of bomb debris, d,	74	74	74	74	25	25	25
Total beta, uuc/l,	500	500	920	920	2830	2830	2830
Dissolved beta, uuc/l,	120	120	630	630	1430	1430	1430
I ALUM COAGULATION							
Clay added, ppm,	--	--	--	--	13	13	53
Alum added, ppm,	20	27	20	27	20	40	20
Lime added, ppm,	--	--	--	--	--	13	--
Floc formation,	3x	3x	3x	3x	2x	3x	x
pH,	5.8	5.4	5.2	4.9	5.5	10.7	5.5
Ia ALKALINE COAGULATION							
Lime added, ppm,	80	16	16	32	16	--	16
Alum added, ppm,	16	--	--	--	16	16	16
Floc formation,	4x	4x	4x	4x	4x	3x	4x
pH,	9.7	9.1	9.2	10.2	8.2	10.2	7.8
TOTAL BETA REMOVAL, %							
I Alum Coagulation	95	76	36	34	60	59	59
Ia Alkaline Coagulation	70	81	38	39	71	57	76
DISSOLVED BETA REMOVAL, %							
I Alum Coagulation	81	0	6	3	20	20	20
Ia Alkaline Coagulation	(-25)	21	10	11	43	15	53

Table 6: Coagulation of Surface Water and Soil Leachings

TEST	1	2	3	4	5	6	7
SOURCE*	River	Lake	CL	SL	SL	CL	SL
QUALITY OF WATER							
Total solids, ppm,	330	244	161	--	144	153	106
Dissolved solids, ppm,	210	230	143	400	130	88	94
pH,	9.8	9.2	8.0	7.8	7.6	7.7	7.3
Age of bomb debris, d,	22	22	14	14	14	12	12
Total beta, uuc/l,	164	340	322	--	630	3770	5740
Dissolved beta, uuc/l,	50	190	290	310	520	1370	2460
I ALUM COAGULATION							
Clay added, ppm,	57	43	27	27	27	--	27
Alum added, ppm,	29	21	13	13	13	30	27
Lime added, ppm,	--	--	--	32	--	--	--
Floc formation,	4x	4x	4x	x	2x	4x	4x
pH,	8.6	7.9	7.6	7.0	7.1	6.7	6.6
Ia ALKALINE COAGULATION							
Lime added, ppm,	--	--	32	40	32	18	16
Alum added, ppm,	--	--	16	--	16	--	--
Floc formation,	--	--	4x	3x	4x	4x	4x
pH,	--	--	7.2	9.7	6.8	8.3	8.9
Ib EXCESS LIME COAGULATION							
Lime added, ppm,	--	--	40	40	40	--	--
Floc formation,	--	--	4x	3x	4x	--	--
pH,	--	--	10.1	9.7	10.1	--	--
TOTAL BETA REMOVAL, %							
I Alum Coagulation	30	48	43	--	57	65	73
Ia Alkaline Coagulation	--	--	53	--	49	72	76
Ib Excess Lime	--	--	46	--	56	--	--
DISSOLVED BETA REMOVAL, %							
I Alum Coagulation	(-130)	8	36	--	48	6	38
Ia Alkaline Coagulation	--	--	48	26	38	26	44
Ib Excess Lime	--	--	40	32	46	--	--

* CL and SL are leachings of Cincinnati rains through 2-inch beds of clay loam and sandy soil, respectively.

Table 7: Summary of Coagulation of Rain, Cistern Water and Surface Water

Table No.	T.Solids ppm	Type Sample	Diss. beta Range uuc/l	Chemical Range* ppm	pH Range	Percentage Removals: Total Beta Range	Total Beta Average	Dissolved Beta Range	Dissolved Beta Average
1	41-151	Rain	185-1630	13- 57	6.4- 7.3	71-84	76.7	0-35	20
				61- 87	5.3- 5.4	71-77	74	3-25	14
				90	8.2	84			(-15)
2	24- 94	Rain	1300-9600	13- 40	5.2- 6.0	62-83	76.3	8-63	35.5
				29- 56	7.8- 9.8	62-86	72.7	(-40)-69	20.0
3	65	Cistern	1180	20- 40	6.9- 8.4	62-70	65.2	21-30	26.2
				20- 47	6.2- 7.0	63-67	65.1	22-31	27.2
				13- 40**	4.3- 5.7	57-62	60.3	10-27	22.7
				52- 72[b]	10.6-10.6	54-72	64.7	4-42	27.4
				40- 67	10.1-10.6	62-69	65.3	22-36	27.7
4	43	Cistern	1910	20-40	6.6- 7.7	65-71	67.5	38-51	43.8
				46- 53[b]	6.7- 7.0	45-60	51	8-33	18.0
				26- 60**	4.9- 9.0	58-64	60.7	30-40	34.3
				59- 66	10-2-10.7	69-72	70.3	48-53	50
				53- 73	9.2- 9.8	69-81	75.0	48-68	58.5
5	77-188	Cistern	120-1430	20- 27	4.9- 5.5	34-95	60	0-81	21.4
				36-100	8.2-10.2	38-81	61.5	neg-53	18
6	200-474	Surface	50-2460	63- 45	6.6- 8.6	30-73	53	neg-48	22
				43- 85	7.2- 9.7	49-76	57	26-44	37.5
				101-125	9.7-10.1	46	46	32-46	39.3

* Lime + TSP + alum or $Fe_2(SO_4)_3$
** $Fe_2(SO_4)_3$
[b] TSP lime & alum

Table 8: Chemical Coagulation of Soil Extracts

PARAMETER	Distilled Water (12 extracts)		Carbonated Water (6 extracts)	
	Range	Average	Range	Average
EXTRACT TESTS				
Beta activity, uuc/ml,	54.6-484	227	72.7-243	136.1
Dissolved solids, ppm,	---	---	370-680	480
Total solids, ppm,	100-780	414	630-1160	840
pH,	8.0-9.0	---	6.4-6.5	---
ALUM COAGULATION (30 min.)				
Alum added, ppm,	80-120	92	40-40	40
pH,	6.1-7.4	---	6.4-6.6	---
Decant beta, uuc/ml,	3.2-60	23.1	---	---
Filtrate beta, uuc/ml,	2.6-51.5	20	11.8-73	35
Beta removal, %	70-97	91.2	70-84	74.3
ALUM PLUS LIME COAGULATION (30 min.)				
Lime added, ppm,	40-40	40	400-620	510
Alum added, ppm,	---	---	80-80	80
pH,	8.9-10.4	---	8.4-10.6	---
Filtrate beta, uuc/ml,	6.6-80	33.9	5.7-25	13.7
Beta removal, %	56-94	85	88-92	90

Table 9: Alum and Lime-Alum Coagulation of Soil Extracts

EXTRACT NO.	1	2	3	4	5&6	8	7
ANALYSIS OF EXTRACT							
Suspended solids, ppm,	550	310	2000	14	110	185	170
Dissolved solids, ppm,	410	290	200	150	150	260	460
pH,	8.0	8.1	7.6	6.8	8.0	8.0	7.8
Beta Activity, uuc/ml							
Total	177.4	141.8	351	9.89	19.5	24.9	40.7
Dissolved	15.4	11.85	6.12	3.62	4.22	9.0	12.1
ALUM COAGULATION							
Alum added, ppm,	40	40	80	80	40	40	40
pH,	7.0	7.4	7.0	4.5	6.9	7.1	6.8
Filtrate beta, uuc/ml,	10.25	7.7	4.0	0.93	2.15	6.8	6.88
Beta removal, %,							
Total	94.2	94.6	98.9	90.6	89.0	72.6	83.1
Dissolved*	33.5	35.0	34.6	74.3	49.0	24.6	43.2
Strontium-90, uuc/ml,	1.19	---	---	0.14	---	0.99	1.0
Sr-90 in filtrate, %,	11.6	---	---	15.1	---	14.5	14.5
LIME-ALUM COAGULATION							
Clay added, ppm,	---	40	40	---	---	40	---
Lime (CaO), ppm,	56	56	56	45	56	56	224
pH,	10.6	10.0	11.1	10.3	10.7	10.5	10.7
Alum, ppm,	40	60	40	40	20	60	---
pH,	9.5	7.6	9.9	9.6	10.6	9.5	10.7
Filtrate beta, uuc/ml,	12.7	7.3	3.6	1.44	2.94	5.2	2.2
Beta removal, %,							
Total	92.8	94.9	99.0	85.4	85.0	79.1	94.6
Dissolved*	17.6	38.5	41.1	60.2	30.4	42.4	81.9
Strontium-90, uuc/ml,	0.27					0.54	0.16
Sr-90 in Filtrate beta, %,	2.1					10.4	7.3

* - Assuming 100% removal of suspended activity.

Table 10: Correlation of Removal with the pH of Coagulation

Type Sample		Percentage total beta removal for coagulation pH of 4-7	7-9	9-11
		Number of coagulation tests		
	Extracts	3	5	6
	Rain	11	9	-
	Cistern	23	14	25
	Surface	3	25	4
SOIL EXTRACTS	Range	83-91	73-99	79-99
	MEDIAN	89	95	90
	Average	87	91	89
RAIN WATER	Range	62-84	59-86	--
	MEDIAN	77	77	--
	Average	77	74	--
CISTERN WATER	Range	34-95	48-76	30-76
	MEDIAN	62	62	62
	Average	62	66	65
SURFACE WATER	Range	49-73	30-76	46-56
	MEDIAN	--	53	--
	Average	62	54	51

		Percentage dissolved beta removal for coagulation pH of 4-7	7-9	9-11
SOIL EXTRACTS	Range	43-74	25-38	18-82
	MEDIAN	49	35	42
	Average	55	33	46
RAIN WATER	Range	(-8)-63	(-40)-69	--
	MEDIAN	30	27	--
	Average	26	16	--
CISTERN WATER	Range	0-81	13-48	(-25)-49
	MEDIAN	26	30	27
	Average	25	34	29
SURFACE WATER	Range	6-38	(-130)-48	26-46
	MEDIAN	--	36	--
	Average	27	35	36